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GLACIER LOG HOMES PROJECT REPORT

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GLACIER LOG HOMES PROJECT REPORT

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ABSTRACT

On June 15, 1986, the Department of Natural Resources and Conservation entered into a grant agreement with Glacier Log Homes, Inc. of Whitefish, Montana. The original intent of the agreement was to demonstrate the economic and technical viability of a dehumidification dry kiln employing an electric heat pump (compressor-refrigeration unit) to dry 6"-by-6" and 6"-by-8" western softwood green timbers to a moisture content of 17 percent of oven-dry weight within 10 days. Toward this end, DNRC ultimately paid Glacier Log Homes (Grantee) $108,769.61 of a projected $117,000 total grant amount; the Grantee invested approximately $50,000 ($31,800 documented, the balance estimated) of Glacier Log Homes's funds to construct the dry kiln, fuel delivery system, and controls.

As actually built, the kiln system differs significantly from the originally intended design and is unable to achieve the target drying time. The system consists of a wood-fired, forced-air, low-temperature dryer with a holding capacity of 40,000 board feet (BF) of timber. It is heated through an air-to-air heat exchanger by flue gas from a modified Dutch oven fueled by headrig sawdust; kiln humidity is not controlled. It takes about 30 days to dry (to 17 percent moisture content and with kiln temperatures not exceeding 110°F) 6"-by-6" and 6"-by-8" timbers cut from partially air-dried logs of lodgepole pine, white pine, spruce, fir, and larch. Connected electric motors total 62 horsepower (HP). If the kiln is continuously operated, kilning costs (including fuel, labor, maintenance, utilities, depreciation, overhead, and return on capital) likely will total approximately $85/thousand board feet (MBF) dried. Because of log shortages, however, the kiln probably will operate only intermittently in the immediate future.

INTRODUCTION

Montana's sizable log and timber homes industry continues to grow. Most of the homes sold are erected out of state, and many homes are exported to Japan and Korea. During 1988, Montana log home manufacturers had aggregate gross annual sales of about $30 million (Keegan et al. 1991). The energy-conserving, thermal-mass effect for heavy log and timber walls in residential construction is of particular interest to energy-conscious consumers (Log Homes Council n.d.).

Because of the nature of log home construction, logs should be dried to equilibrium with the atmospheric conditions under which the log structure ultimately will serve; this equilibration reduces shrinkage in wall height after erection to an acceptable level. The atmospheric condition may vary from 10 percent relative humidity (e.g., eastern Montana or Arizona during the summer) to 90 percent (e.g., Louisiana, Mississippi, or other warm, humid maritime climate areas). The corresponding equilibrium moisture content (EMC) of the wood comprising the logs in the structure may range from 3 to 20 percent of the wood's oven-dry weight. In North America, average EMC in unheated wood structures generally is considered to be about 12 percent of the wood's oven-dry weight. This average ultimately is reached, for example, at a dry-bulb temperature of 70°F and relative humidity of 65 percent. In homes, interior heated walls commonly range from 3 to 10 percent moisture content, and exterior walls from 12 to 20 percent.

For log home manufacturers, these low moisture contents are difficult to reach, and most manufacturers likely ship logs and heavy timber comprising log home kits at a moisture content of about 17 percent of oven-dry weight. In Montana, since outside air temperatures and humidities vary widely among seasons, generalization about drying rates is not possible. As an example, however, if logs are equilibrated for a sufficient time—a matter of months—at a dry-bulb temperature of 70°F and relative humidity of 82 percent, they ultimately will reach equilibrium at about 17 percent moisture content.

To place this problem in better perspective, the stemwood of live trees standing in the forest—or freshly harvested—contains about half water. For example, if a fresh green log weighs 100 pounds, half of that weight—or 50 pounds—typically is water (Koch 1987). To use wood technologists' terminology, such wood is said to have 100 percent moisture content; that is, the water in the wood weighs 100 percent of the weight of the oven-dry wood.

When wood is being dried, it does not begin to shrink until it reaches about 28 percent moisture content. As the soft woods typically used in log home construction dry from 28 percent moisture content to 0 percent moisture content (oven-dry), they shrink radially to the log axis about 4.3 percent. A log wall 100 inches high built from green logs will therefore shrink from its 100-inch height to a 95.7-inch height if the logs are completely oven-dried. This shrinkage is approximately linear with moisture loss between 28 and 0 percent moisture content. Thus, this 100-inch-high log wall will begin to shrink when log moisture content reaches 28 percent, and by the time moisture content has dropped to 14 percent, the wall height will have been reduced to 97.8 inches. At 17 percent moisture content, the wall height will not have been reduced quite so much—probably to about 98.3 inches. Tangential (circumferential) shrinkage in logs is about 6.7 percent from green to oven-dry; this is the shrinkage that opens longitudinal checks (cracks) in log surfaces.

The foregoing discussion explains why window and door frames and interior wall facings (which do not shrink appreciably in height with changes in moisture content) are best installed after log shrinkage has taken place. Thus, log and timber moisture content must be reduced to an acceptable level before house kits are shipped to consumers.

Now consider how much water must be evaporated. A cubic foot of lodgepole pine logs (oven-dry wood only—no water) of the diameter commonly used for house logs weighs about 25 pounds. This same cubic foot from freshly cut, live lodgepole pine trees also contains about 25 pounds of water. (A family-size log home might be comprised of 800 cubic feet of logs and timbers.) To dry one cubic foot from the green condition (100 percent moisture content) to 17 percent moisture content requires evaporation of 20.75 pounds of water (83/100 x 25).

Since the relationship of energy to dry logs is more or less linear to the amount of water to be evaporated, log home builders understandably prefer to acquire standing dead timber that has air-dried on the stump and lost a significant amount of its water. Data from Lowery and Hearst (1987) suggest that lodgepole pine killed by bark beetles or fire and left on the stump for a year or more will attain a moisture content below the fiber saturation point (28 percent of oven-dry weight). If sawed into lumber, the wood will yield 2"-by-4" studs with a moisture content of about 24 percent of oven-dry weight. During drying—whether on the stump, in an air-drying yard, or in a kiln—logs or heavy timbers will check. If not too severe, however (e.g., less than 1/4-inch wide and less than one full turn of spiral grain), this defect usually is acceptable to the log home builder. Less acceptable to some is the severe blue stain accompanying a beetle attack and extended drying on the stump.

In any event, for one cubic foot of logs to reach 17 percent moisture content requires the evaporation of 1.75 to 20.75 pounds of water, depending on whether the logs have been dried on the stump (as dead trees) or freshly cut from live trees. The heat energy required to evaporate a pound of water at atmospheric pressure is at least 970 Btu (British thermal units). Therefore, at 100 percent efficiency, theoretical minimum heat required to evaporate the desired amount of water from one cubic foot of logs ranges from about 1,698 to 20,127 Btu, depending on the initial moisture content of the logs. In actual practice, however, the amount is significantly greater because logs are cool, fan energy is needed to move air, and heat losses from kilns are substantial. Also, kiln heat losses positively correlate with residence time in the kiln; that is, heat losses are greater for long kiln schedules than short.

In conventional and high-temperature kilns for large-scale drying of southern pine lumber, 3 million Btu/MBF of green lumber dried to market moisture content is a commonly used estimate of total energy requirement (Wengert and Beckwith 1989). If kiln schedules are long protracted— usually the case when drying timbers—energy consumption can be much greater.

Generalization about the heat requirement of a kiln drying lodgepole pine, white pine, spruce, fir, and larch house logs and heavy timbers is difficult. This difficulty arises in spite of fixing the ending moisture content at 17 percent, because the starting moisture content may vary from 100 percent of oven-dry weight for fresh green wood to about 24 percent for wood air-dried for long periods. Also, the ambient wood and air temperatures may vary from below 0°F in winter to perhaps 80°F in summer. Thermal heat supply to a kiln must meet maximum demand, however. If green log and timber input is assumed, and the overall kiln thermal efficiency is 40 percent, one cubic foot of logs or timbers will require about 50,318 Btu of heat energy to dry this cubic foot to 17 percent moisture content. Fan energy to circulate kiln air, provide combustion air, and furnish furnace draft, along with energy to operate fuel conveyors, must be provided in addition to the thermal energy.

A pound of wood (oven-dry) contains about 8,600 Btu. When heat exchangers are used in conjunction with wood-burning furnaces, the combined efficiency of combustion and heat transfer may fall within a range of 60 percent with green fuel to 70 percent with dry fuel. If wood fuel has been partially dried, combined combustion and heat transfer efficiency is estimated at 65 percent.

Providing the 50,318 Btu of heat energy required to dry one cubic foot of green wood to 17 percent moisture content, therefore, requires about 9.0 pounds (50,318/8,600/0.65) of woody, air-dried fuel (oven-dry weight basis). For thoroughly air-dried timbers (24 percent moisture content) dried to 17 percent moisture content, fuel demand will be reduced significantly. If kiln schedules are greatly extended—frequently the case when drying timbers that permit minimal checking— fuel consumption may be increased significantly.

The time needed to air-dry logs and timbers is measured in months. As a result, air-drying can be expensive because of the cost of carrying large log inventories and because significant land acreage is required for this type of drying. To reduce log inventories and log-yard acreage, and to control moisture content in logs and timbers shipped, log home builders are interested in the kiln-drying process. This interest in kiln-drying and the energy consumption of kilns for logs and timbers provided the driving force behind the Glacier Log Homes project.

PROJECT HISTORY

BACKGROUND

A review of the correspondence and documents (February 1986 through March 1991) related to the Glacier Log Homes project suggests that objectives were not clear at the outset. It seems to have been an early intent of Glacier Log Homes, Inc. (Grantee) to build a dehumidification kiln. To the extent to which the ultimate system departed from this intent, a discussion of the principle of operation of dehumidification dryers is useful. Wengert et al. (1988) describe the dehumidification kiln as follows:

> The dehumidification dry kiln offers a method of drying wood (i.e., controlling the temperature and humidity) without using a large boiler for heat and humidification and without using vents for lowering the relative humidity. Instead of steam and venting, the dehumidifier uses electricity to cool the air and thereby condense moisture from the air. In addition, because there is a large amount of heat released when water is condensed, the dehumidifier recycles this heat into the kiln to evaporate moisture. The equipment used is a heat pump (also called a compressor or refrigeration unit). The heat pump operates on the same principle as a window air conditioner or a compressor in a refrigerator. Figure 1 [see page 4] shows damp air being withdrawn from the kiln. (Not all the air is withdrawn—only a small portion of it.) This air is passed through the cold coils (also called the evaporator coils) of the compressor. The humid air cools and as it cools below the dew point, moisture is condensed. The colder the coils, the more that will be condensed. When this moisture is condensed, it releases the heat of condensation—identical to the amount of heat that was required to evaporate the water from a dish. The compressor then pumps this heat to the hot coils. (In an air conditioner or refrigerator, the hot coils are outside.) The dried air from the kiln is then passed over these hot coils, picking up this energy of condensation. In heating the air, its humidity is lowered. If the temperature difference between the hot coils and cold coils is 50 degrees F., then the humidity of the exiting air will be about 15% RH. The air then enters the kiln, passes through the stack of lumber, evaporating more moisture, and eventually back to the dehumidifier.

Experts advise that dehumidifying dryers are best used in applications where:

- small-scale drying is contemplated (chambers typically hold 30 MBF of wood)
- fuels alternate to electricity are not available
- electricity costs are low [less than $0.07/kilowatt hour (kWh)]

With dehumidification drying of timbers, temperatures would not exceed 150°F (only certain grades of refrigerant will permit such a high temperature). In very permeable woods such as southern pine, drying 6"-by-6" timbers to 17 percent moisture content should take about 15 days. With impermeable softwood such as lodgepole pine heartwood, drying time likely would take 30 days, and temperatures would be lower—perhaps less than 120°F. The compressor on this type of dryer of impermeable wood

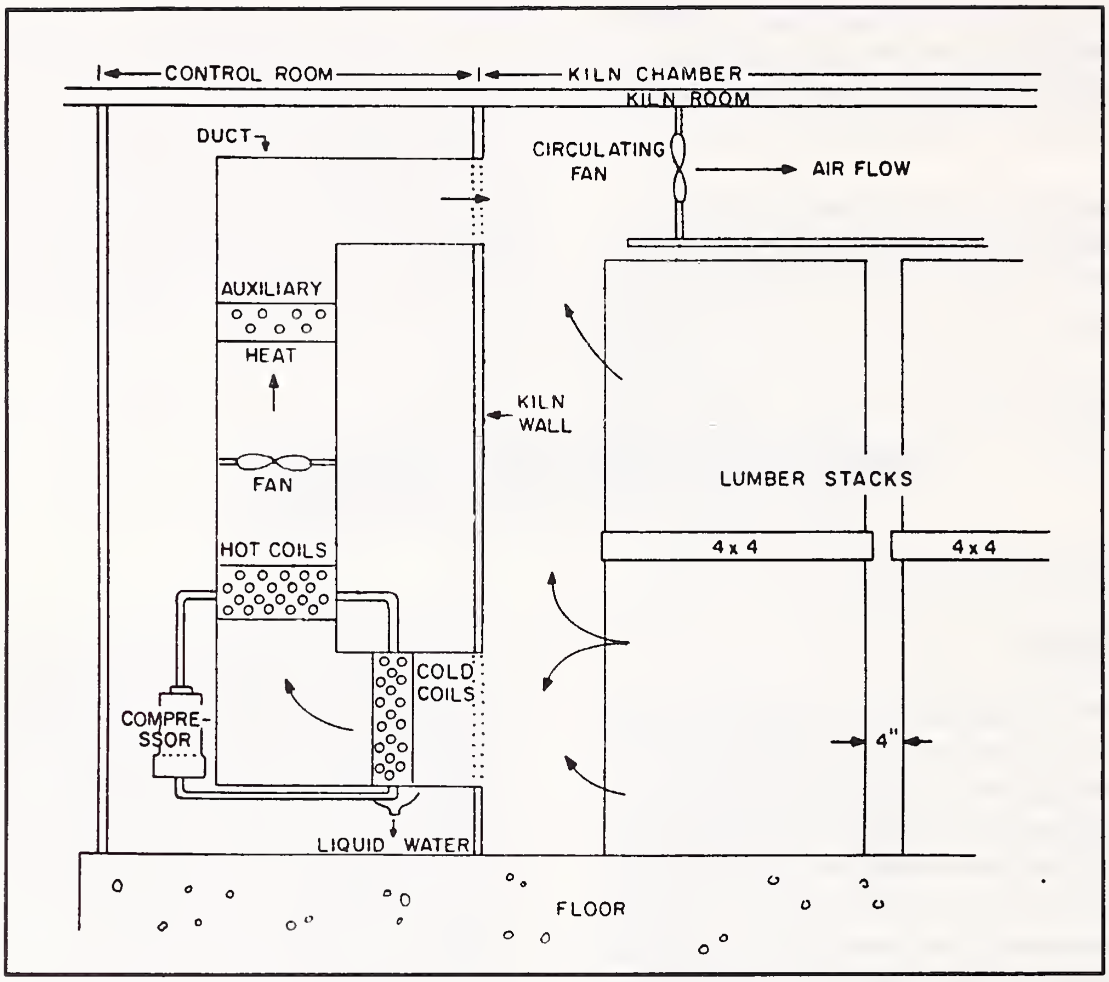

Figure 1. Schematic diagram of a dehumidification dryer. Drawing from Wengert et al. (1988).

usually is sized with one HP per MBF holding capacity in the kiln. Capital cost for compressors is about $1.50/BF of kiln holding capacity of impermeable wood. Total cost of the kiln and compressor for 40 MBF holding capacity of relatively impermeable wood (such as lodgepole pine) is about $120,000.

To supply the auxiliary heat sometimes needed (see Figure 1), and to supply high humidity for conditioning timbers at the end of the drying cycle, a small electric boiler commonly is used (the compressor is shut off during this conditioning cycle). Alternatively, the small auxiliary boiler is fired with natural gas or propane.

As previously noted, the water output per MBF of wood dried is considerable—about 250 gallons. This condensed water—usually slightly acidic—is sewered, sometimes being chemically neutralized first with soda ash.

At least 500 such kilns operate in North America. Three well-known manufacturers are:

- Uraken, St. Eustache, Quebec, Canada
- Dry Line System, Mississauga, Ontario, Canada
- Nyle Corporation, Bangor, Maine, United States

The following discussion will focus on events involved with the Glacier Log Homes project and abstracts related correspondence. (A chronological list of communications related to the project begins on page 22.)[1]

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[1] These documents and others mentioned throughout this report that relate to the Glacier Log Homes project are on file at the Department of Natural Resources and Conservation in Helena.

CHRONOLOGY OF EVENTS

In early 1986, Machinery Market, Inc. of Portland, Oregon, submitted to DNRC copies of proposals made to the Grantee related to:

- Hurst Boiler Company for solid-fuel-fired box boiler, 15 psi, hand-fired
- Olivine direct-fired Dutch oven burner
- 30 MBF kiln chamber
- 60 MBF kiln chamber
- A dehumidification system with refrigeration compressor and with 30 MBF kiln—all controlled by micro-computer

Information from Machinery Market included an essay (dated June 10, 1981) by Donald C. Lewis, president of Nyle Corporation in Bangor, Maine, describing "heat pump energy recovery in conventional dry kilns." In an accompanying letter dated October 2, 1985, to Lincoln Precut Log Homes in Kirkland, Washington, Richard H. Elliot of Nyle Corporation advised Lincoln Precut Log Homes: "Drying time on your spruce 6-inch by 9-inch (timbers) to 15 to 18% moisture content would be approximately 10 days. It will take a little longer on frozen stock."[2]

In May 1986, the grant was negotiated to include a dehumidification kiln with electrically driven compressor-refrigeration and a biomass combustor to use the Grantee's headrig sawdust for kiln startup heat. DNRC reviewed and agreed to this, and also agreed to its budget of $117,108. The amount of $51,000 was included for an Olivine furnace and accessories, along with $50,000 for the dehumidification (compressor-refrigeration) system. On June 27, DNRC sent Grant Agreement No. RAE-86-1070 to the Grantee for signature, and on July 8 the Grantee received the fully executed agreement. June 15, 1986, was designated as the official date of the agreement.

The agreement indicates that the Grantee will demonstrate the technical applicability and economic viability of a wood-fired kiln used to dry rough-sawed green cants, and that the Grantee will use its own funds to build the kiln. DNRC will fund the hot air furnace, the heat dehumidification units, and support equipment, including monitoring equipment. The system is to be designed to dry 60 MBF of undried (green) product to a final moisture content of 17 percent within 10 days. The agreement also stipulates: "If the kiln operation is economically feasible in this application as determined by the analysis defined in Milestone 5, the Grantee shall repay to the Department all Grant funds received under this Agreement."

Grant Agreement No. RAE-86-1070 describes Milestone 1 as a report that defines the entire system's design and specifications as it will be built, along with equipment delivery and construction schedules. Estimated completion date of Milestone 1 is August 1, 1986, at a cost not to exceed $31,450. Upon DNRC's approval of the system, the Grantee is to order the equipment components and submit vendor invoices for reimbursement by DNRC.

Milestone 2 calls for development of a system monitoring program and an instrumentation package (work may be subcontracted). Estimated completion date of Milestone 2 is September 15, 1986, at a cost not to exceed $2,550. Upon DNRC's approval of the system, the Grantee is to order the system monitoring components and be reimbursed by DNRC upon delivery.

Milestone 3 calls for kiln construction and furnace and dehumidification system installation, followed by an on-site inspection by DNRC. Estimated completion date for Milestone 3 is December 31, 1986, at a cost not to exceed $75,850. The total cost of DNRC's outlay for the first three milestones is $109,850.

Milestone 4 calls for purchasing and installing the DNRC-approved monitoring equipment approved in Milestone 2, calibrating the instrumentation, and collecting data "for a short term...from a few days to a few drying runs...and shall interpret the data to assess proper operation...." In addition, the Grantee shall "conduct drying runs to determine furnace performance using biomass fuels and record data identifying drying efficiency and overall energy balance." DNRC will send a representative to inspect the monitoring equipment and review the preliminary data to ensure that proper data systems are in place. The Grantee shall retain a technical representative to maintain the monitoring equipment and ensure that data acquisition is complete. The Grantee will prepare a summary report of findings (with raw data appended) for DNRC approval. Estimated completion date for Milestone 4 is March 1, 1987, at a cost not to exceed $4,850.

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[2] This reviewer suggests that an alarm might have been sounded here, questioning the Elliott conclusion—particularly for lodgepole pine cants green from the headrig. The 10-day, kiln-dwell time most probably is unrealistic.

Milestone 5 calls for monitoring the system during at least four months of continuous operation during the peak drying season, maintaining cost records, and preparing a summary report of findings and an evaluation of the project's economics. This section of the agreement explains the grant repayment formula in terms of avoided costs of yard-drying, custom-drying, and decreased production costs of cants. The repayment schedule will be reviewed jointly by the Grantee and DNRC, with total repayment of $110,150. All prior milestone data will be assembled into a single final report with summary statement; contents of the final report are explained in detail. The estimated completion date for Milestone 5 is August 1, 1988, at a cost not to exceed $2,400, thereby concluding the agreement at a total cost to DNRC of $117,100.

During July (probably 1986), with no forewarning in the file of communications (possibly because the file is incomplete), a series of purchase agreements were made between the Grantee and Ultrafire West of Victor, Montana, for the following equipment:

• Ducting and humidity components	$64,428.93
• Heating system, installed (this is a furnace for burning sawdust installed complete with rotary feed valve, combustor, plenum, flues, and draft inducer)	$19,372.25
• Control system	$ 8,599.50

Through these purchase agreements, the condenser-refrigeration dehumidification system is abandoned and replaced by a system that circulates ethylene glycol through a fan-cooled, 3-foot-square radiator external to the kiln. The ethylene glycol then is circulated through two additional large radiators internal to the kiln-air plenum to chill half of the warm, moist air leaving the kiln and condense water from it to flow into a pit to a sewer.[3,4]

Presumably, at the time the foregoing purchase agreements were signed, Ultrafire West provided the Grantee with five sheets of drawings. (See DNRC file RAE 91-1073 II for these drawings.) These drawings described the kiln construction (in transverse section) and general layout of the sawdust combustor, flue-gas flow around the kiln-air heat exchanger, the condenser radiators, and the kiln-air circulation pattern through the kiln (top to bottom of kiln, reversible). The drawings also indicated that kiln air was driven by two 12,500 cubic-foot-per-minute fans (Milestone 1 report indicates two 30-inch, 5 HP fans with combined air flow of 37,000 cubic feet per minute intended to yield a within-kiln-stack velocity of 480 feet per minute). No kiln roof vents are incorporated into the design. As ultimately built, the kiln's inside dimensions were 20.5 feet wide, 27 feet long, and 14 feet high; according to the Grantee, the kiln will hold 40 MBF of spaced timbers stacked on kiln sticks. The kiln is designed to be loaded with a fork lift through an 18-foot-wide end door.

A sawdust storage bin measuring 7 feet in outside diameter and 32 feet high then was purchased. This tank, which has thick steel walls, was designed for a purpose other than storing sawdust. The Grantee burned out the tank's interior lining and cut an exit hole near the bottom to receive the conveyor to the hopper and rotary feed valve over the combustor. The Grantee then installed several hydraulically actuated (5 HP), ladder-like steel pokers suspended at their top ends to alternately oscillate

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[3] At this point, this reviewer finds the first indication of a radical departure from the system originally contemplated.

[4] It seems to this reviewer that little or no condensation is possible with this system during summer months because summer ambient air temperatures may frequently exceed 70°F, and final kiln temperature is about 70°F. In fact, this aspect of the system was tested only once and then shut down permanently. (It would be interesting to measure the condensation achievable in winter weather at 0°F.)

vertically within the sawdust bin to prevent bridging. The Grantee reports that this strategy works well, and bridging in the 32-foot-high sawdust tank is avoided.

On September 18, 1986, the Grantee submitted the Milestone 1 and Milestone 2 reports (see DNRC files RAE 91-1073 III and IV) and requested DNRC approval of the system design. Enclosures included vendor invoices and the Ultrafire West drawings.

On October 24, 1986, DNRC advised the Grantee that Milestone Reports 1 and 2 showed significant differences from the system described in the original agreement. As a result, design approval was denied pending system review, and additional questions were raised regarding the system.

On December 9, 1986, DNRC approved the system changes described in the Milestone 1 report, executed an amendment (No.1) detailing these changes, and shortly thereafter paid the invoice for Milestone 1.

In Amendment No. 1, the kiln building is said to measure 28 feet wide by 28 feet long by 14 feet high. Estimated completion dates for milestone reports were changed as follows: No. 1, November 1,1986; No. 2, January 31, 1987; No. 3, May 1, 1987; No. 4, June 15, 1987; and No. 5, September 30, 1988.

By March 19, 1987, DNRC concluded that Milestone 2 was completed, and shortly thereafter paid the Grantee.

In a March 30, 1987 progress report, DNRC noted that the control and monitoring system design was completed, and that the system would be fueled by waste wood produced by the log home manufacturer. The report further noted that the foundation, kiln, and furnace all were in place, and that future efforts would involve monitor control systems and operational testing. A project budget summary sheet attached to the progress report indicated that the kiln building was built by the Grantee at a cost of $31,000 to the Grantee.

On April 6, 1987, DNRC outlined the desired kiln energy monitoring parameters, including:

- Heat content of woody fuel (Btu)
- Combustion, building, and system losses
- Energy required for drying in Btu per kiln charge (calculated by measuring the condensed water collected from the dehumidifier and multiplying that by the latent heat of evaporation)
- Energy required to raise the temperature of the mass of incoming material (wood and water) to the (initial) drying temperature
- Energy picked up by the ethylene glycol at the condensing coils inside the kiln-air manifold (measured by determining the air temperature drop and volume across the external, fan-cooled cooling coils)
- Energy transferred to timbers stacked down-wind of the external, fan-cooled cooling coils (for predrying before admission to the kiln)
- Energy that heats any outside air admitted to the closed kiln-air circulation system—anticipated to be minimal
- Calculation of total energy required per load

On April 8, 1987, the Grantee advised DNRC that Milestone 3 (kiln construction and furnace and dehumidification system installation followed by an on-site inspection by DNRC) was complete and requested reimbursement. On April 30, DNRC approved the invoice for reimbursement (with $5,000 held back at the Grantee's suggestion to cover further equipment costs).

A DNRC progress report dated May 11, 1987, based on an on-site inspection (see DNRC file RAE 91-1073 V), indicated that equipment installation was almost finished. The report concluded that the project's next milestone would be operation of the system and one-year energy monitoring. An independent flue gas analysis to measure combustion efficiency was planned for the next milestone, along with another inspection by DNRC when the furnace was firing.

By late June, 1987, serious problems with the project became apparent. Ultrafire West had not sent parts of the furnace to the Grantee, thus straining the professional relationship between the two companies.

On September 1, 1987, DNRC wrote to the Grantee and indicated that DNRC had requested Ultrafire West to contact the Grantee about completing the start-up phase delineated in the Grantee's agreement with Ultrafire West. DNRC suggested that if this arrangement could not be made, the Grantee should hire another consultant to complete the start-up phase. The letter concludes: "Currently the grant is falling behind schedule. Milestone 3 was to have been completed May 1 with instrumentation installed for monitoring the month after."

During the first half of September 1987, all efforts taken to mediate the dispute between the Grantee and Ultrafire West failed. A DNRC status report dated September 23 indicated that "the fuel handling system, the furnace, and the dehumidified air systems have yet to be integrated before startup of the project." By September 28, DNRC was considering options to salvage the project, including reviewing the names of other consultants that the Grantee might hire.

An on-site inspection report by DNRC dated March 2, 1988, provided the results of data collected January 20, 1988, that permitted computation of combustor system efficiency (see DNRC file RAE 91-1073 VI). The report stated that at no time were any soot or smoke observed from the exhaust stack. Calculated overall efficiency of the combustor system (excluding the air-to-air heat exchanger) was 47.2 percent at low fire and 71.6 percent at high fire. DNRC recommended that the efficiency tests be repeated at a later date when all of the kiln's systems were operating.

Adding to existing problems, a fire destroyed the Grantee's sawmill in mid-July 1988. The kiln building and furnace were not harmed, however. During the week following the fire, the kiln was charged and timbers were drying under a semi-automatic temperature control installed by the Grantee. No computer control was in place, though, nor were humidity controls and the humidifier system operating (they have not operated to this date). The Grantee reported that the kiln would operate until the sawdust fuel was exhausted; the sawmill would be rebuilt.

By the end of July, the kiln had shut down from lack of headrig sawdust for fuel, and the schedule for rebuilding the sawmill remained uncertain. Since the use of other particulate woody fuel would have required a redesign of the furnace feed, this option was rejected. In any event, energy monitoring without automatic controls and instrumentation was considered impossible.

On September 30, 1988, the Grantee requested an extension of the basic grant agreement. On October 27, DNRC sent Amendment No. 2 to the Grantee. To allow time for completion of Milestone 5, the amendment called for termination of the agreement on June 30, 1989. No mention was made of Milestone 4 concerning installation and calibration of energy-monitoring equipment and short-run collections of data on kiln operation.

The file contains no record of any communication during 1989; however, contact was maintained through quarterly reports.

On December 11, 1990, DNRC wrote to the Grantee to obtain the signature of Appendix B to Agreement No. RAE 86-1070, Assignment of Monitoring and Final Reports. The letter noted that no energy monitoring had taken place, nor had Milestones 4 and 5 been completed because various kiln systems such as the humidification and dehumidification systems approved in Milestone 2 never worked. This letter, proposing that a final report be prepared by contracting for the service, was signed by the Grantee December 23, 1990, and by DNRC January 4, 1991.

On March 1, 1991, DNRC prepared a schedule of disbursements to the Grantee, indicating a total of $108,769.61 (see DNRC file RAE 91-1073 VII).

On April 15, 1991, DNRC hired the preparer of this report to summarize the history of the Glacier Log Homes project, describe the system operation, provide some indication of operational expenses as compared to a gas-fired system, and suggest possible improvements with related research needs.

SYSTEM OPERATION

The system as it stands today is fueled by sawdust from an 11/32-inch-kerf, circular-saw headrig cutting partially air-dried (and some green) logs of western white pine, lodgepole pine, Engelmann spruce, Douglas fir, and larch. Products manufactured consist mostly of 6"-by-6" and 6"-by-8" whitewood timbers and various beam sizes of fir and larch, with some yield of thinner sideboards. (See Figure 11, page 15, for a cross-sectional detail of a typical timber product in finished form.) The sawdust is discharged into a rotary feed valve that feeds a 6-inch-diameter conveyor pipe. In this pipe, the fuel is blown about 200 feet (30 HP blower) into either the top of the fuel storage tank (see Figure 2) or to an elevated sawdust bin for discharge to farmers' trucks. The Grantee notes that if repeating the construction, a pipe 4 inches in diameter would be used. From the bottom of the fuel storage tank, the sawdust is conveyed upward into the fuel hopper that feeds the sawdust burner (see Figures 3 and 4 on next page). This conveyor is actuated by a bin level controller in the top of the fuel hopper.

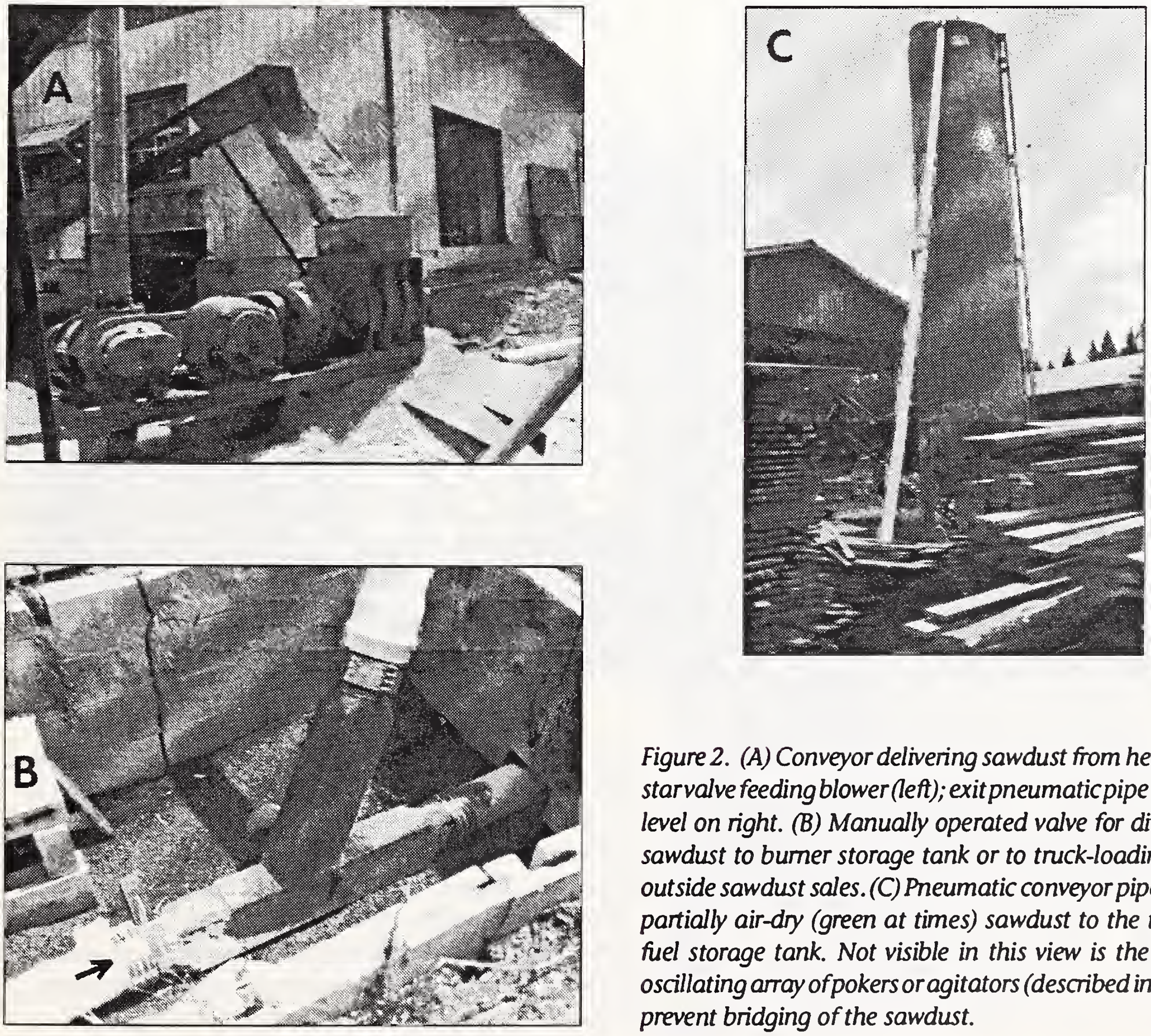
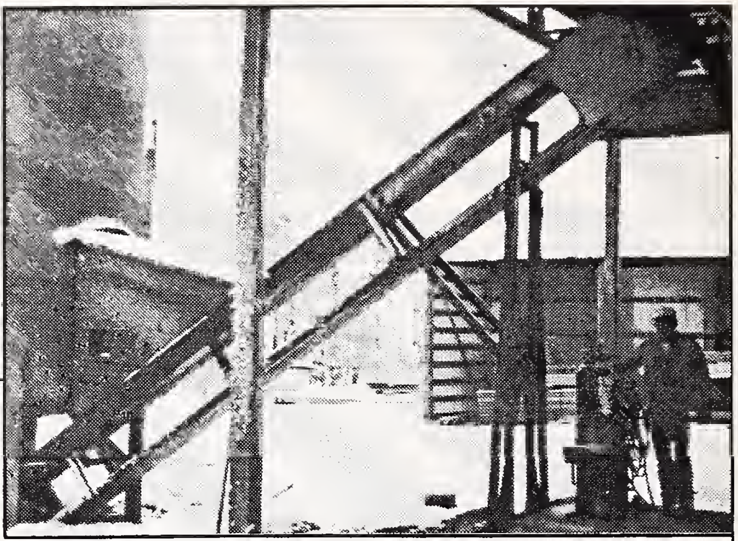


Figure 2. (A) Conveyor delivering sawdust from headrig into starvalve feeding blower (left); exit pneumatic pipe at ground level on right. (B) Manually operated valve for diversion of sawdust to burner storage tank or to truck-loading bin for outside sawdust sales. (C) Pneumatic conveyor pipe carrying partially air-dry (green at times) sawdust to the top of the fuel storage tank. Not visible in this view is the vertically oscillating array of pokers or agitators (described in text) that prevent bridging of the sawdust.

Figure 3. Conveyor carrying sawdust from the bottom of the fuel storage tank to the hopper feeding the sawdust burner (hopper not installed at time of photo).



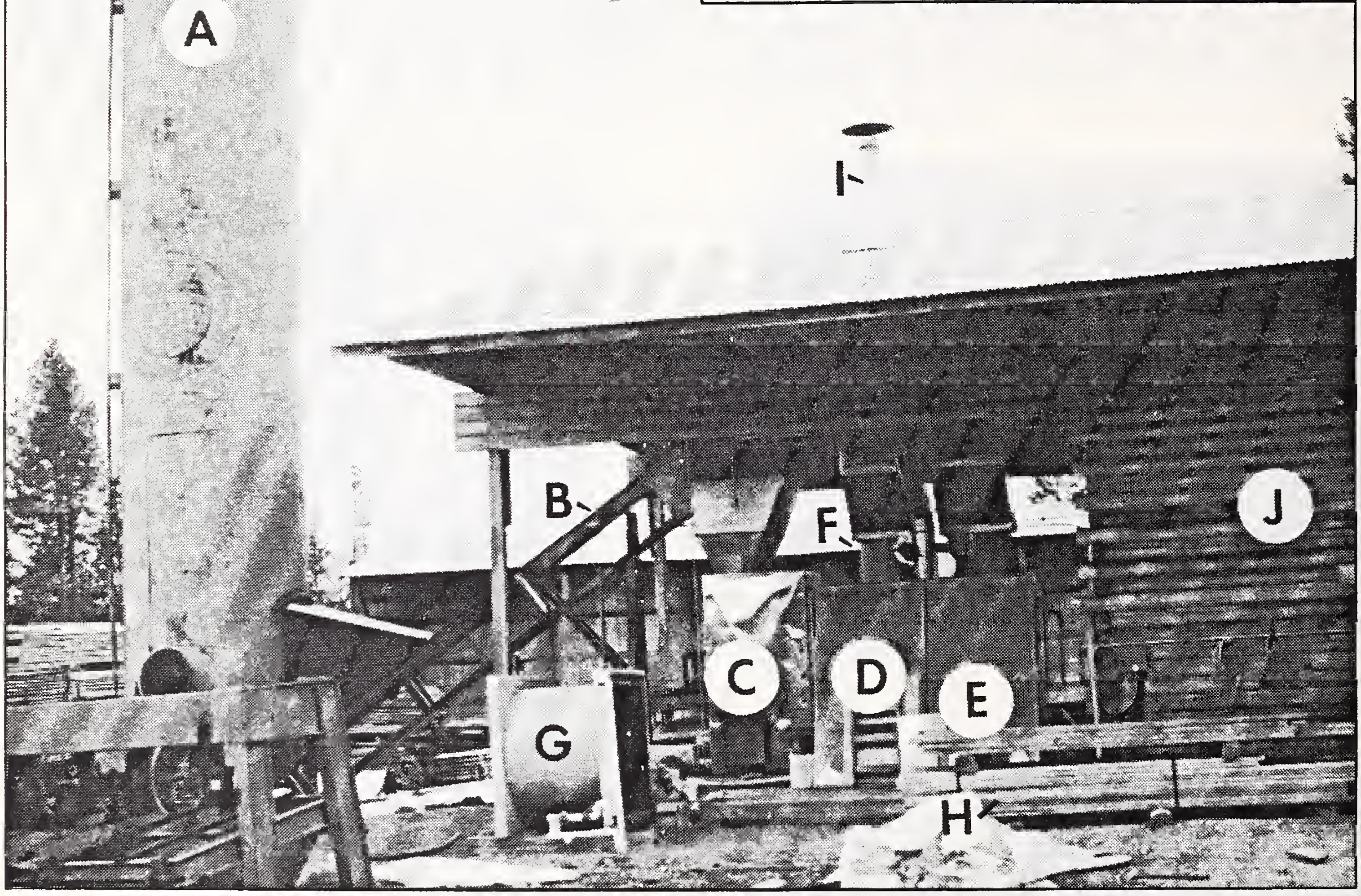


Figure 4. Fuel storage tank (A). Conveyor from fuel storage tank to the hopper feeding the sawdust burner (B). Sawdust burner (C) with furnace floor access door below label and three fire viewing ports into secondary combustion chamber to right, plenum housing the air-to-air heat exchanger between hot flue gas and air to be circulated in kilns (D). Plenum housing the condensing radiators intended to dehumidify kiln exit air (E). Above each of the two plenum compartments (D and E) is a reversible ducted fan (F) that circulates heated (and dehumidified) air back into the kiln. Circulation in the kiln is vertical from floor to ceiling. In the foreground is the fan-cooled radiator (G)—the 5 HP fan is 48 inches in diameter—intended to air-chill ethylene glycol prior to circulating it to the condensing radiators in plenum (E). It was originally envisioned that fan-driven warm air leaving the fan-cooled glycol radiator (G) would blow across and through green timbers stacked down-wind (H) and partially dry them. Cool flue gases exit from stack (I). Heated kiln air is circulated vertically through floor and ceiling ducts in kiln (J).

Heat output from the sawdust burner—a variation of a Dutch oven design (see Figures 4(C) and 5)—is controlled by demand from the kiln. That is, if kiln heat is required to maintain kiln temperature, the sawdust burner combustion fan is turned on in concert with one or both of the induced-draft stack fans, and sawdust combustion accelerates to produce more hot flue gas. This, in turn, heats the circulating kiln air via the air-to-air heat exchanger (see Figure 6). An override switch turns off the combustion air (and provides cooling, fresh air) if a preset maximum flue-gas temperature is exceeded.

A conventional Dutch oven (see Figure 5) is a two-stage refractory (firebrick-lined) furnace. Fuel is fed through a chute in the oven roof and piles on the bottom (grate) of the oven or primary furnace. Here the fuel is dried and partially combusted. The system is designed so that there is insufficient air for complete combustion in the primary furnace. Combustible gases from the burning fuel pile pass into the secondary furnace, or combustion chamber, where air entering through overfire ports completes combustion.

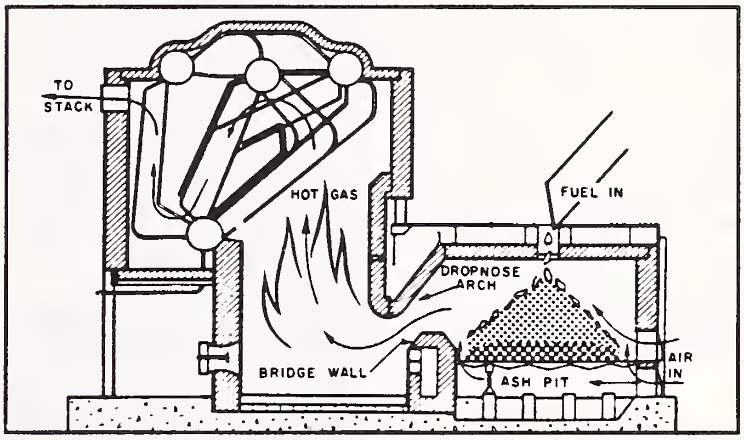


Figure 5. Cross-sectional view illustrating the principle of a "Dutch oven" wood-fueled burner with primary combustion in the sawdust bed and secondary combustion beyond the bridge wall. Illustrated beyond is a water-tube boiler. In the Grantee's design, however, the hot flue gases flow through an air-to-air heat exchanger—Figure 6(A)—before venting to stack. (Drawing after McKenzie 1968).

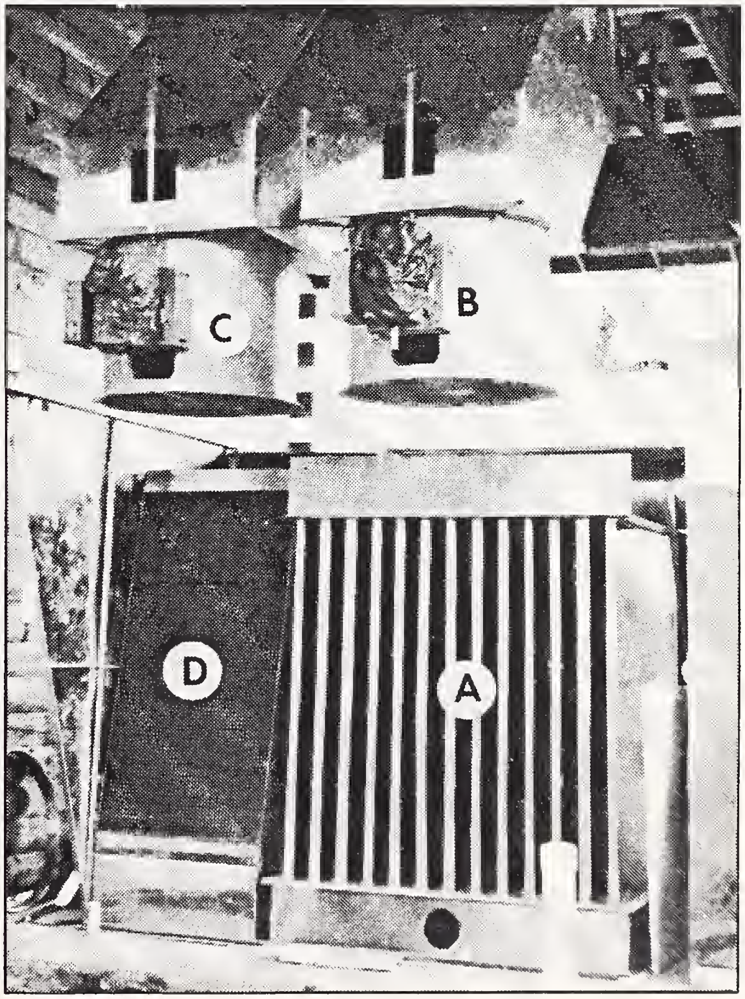


Figure 6. Air-to-air heat exchanger (A) exposed before plenum covers were installed. Flue gases are confined within the stainless steel vertical tubes (passageways); kiln air passes horizontally through the open spaces. The round access hole at the bottom in the cleanout pan permits removal of accumulated ash (very little). Directly above the heat exchanger is the ducted fan housing (B) that carries half the kiln air through the heat exchanger. The other half of the kiln air (C) is blown through the condensing radiators (D) on the left of the assembly for dehumidification before reintroduction to the kiln.

The Grantee's design has no grate or bridge wall. Hot combustion gases, on their way to the stack, exit the secondary combustion chamber several feet above the furnace bottom through a pair of 10-inch pipes to an air-to-air heat exchanger (see Figure 6). This heat exchanger warms air circulated through the dry kiln. In the secondary combustion chamber, flames extend about 2-1/2 feet above the chamber floor.

In conventional Dutch ovens, combustion rates of about 600,000 Btu per square foot of grate per hour have been attained with wood having 80 percent moisture content (that is, 80 pounds of water per 100 pounds of oven-dry wood). The combustion rate, however, drops off rapidly above this moisture-content level. Excess air in the stack usually ranges between 30 and 40 percent. The installed furnace has 3.8 square feet of floor area, suggesting a maximum heat output of about 2.28 million Btu/hour with wood at 80 percent moisture content. The Grantee notes that the temperature of flue gas leaving the secondary combustion zone usually ranges from 1,400° to 1,800°F.

The amount of ash that ever has been removed from the burner is small; most is entrained in the flue gas and exits the stack in a more-or-less invisible plume. Fairly small quantities of ash may accumulate in the cleanout pan at the bottom of the air-to-air heat exchanger.

The Grantee notes that the temperature of flue gas as it enters the air-to-air heat exchanger commonly ranges between 700° and 900°F. Flue gas leaving the heat exchanger and entering the stack is controlled within a range of 250° to 400°F. Temperatures of kiln air leaving the heat exchanger vary with schedule but seldom reach more than 120°F or less than 70°F.

Figures 6 and 7 show two reversible ducted fans (5 HP each). One feeds kiln air into the heat exchanger, and the other feeds kiln air through the condensing radiators within the plenum. In theory, water condensed from moist warm air leaving the kiln should flow down the condensers' surfaces into a sump (see Figure 9 on page 14) for disposal to the sewer. In practice, no water is condensed (the outside, fan-cooled radiator intended to chill ethylene glycol for the condensing radiators within the plenum—Figure 4(H)—is not operational). Conversely, the Grantee's problem is insufficient moisture in the kiln air; this dry air does not permit conditioning of timbers at the end of the drying run. To add moisture to the kiln air during this portion of the kiln run, the

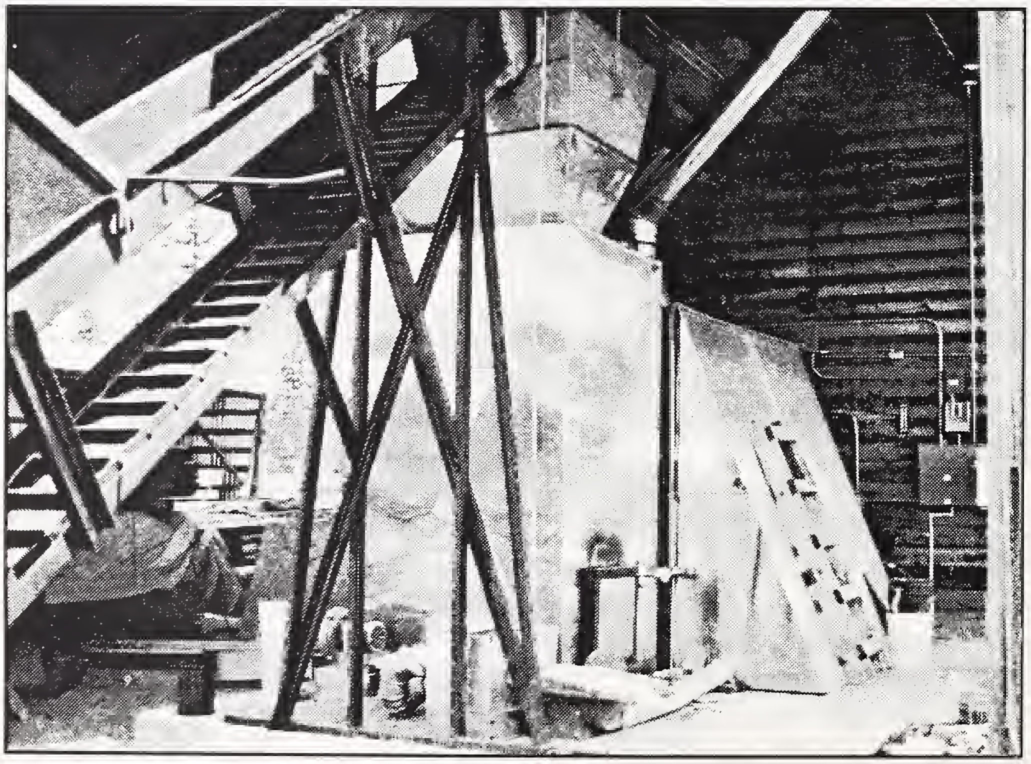


Figure 7. Same assembly shown in Figure 6 but with the plenum covers in place. The sawdust burner is at left, with fuel hopper on top. (Also see Figure 4 for side view with plenum covers and ducted fans in place.)

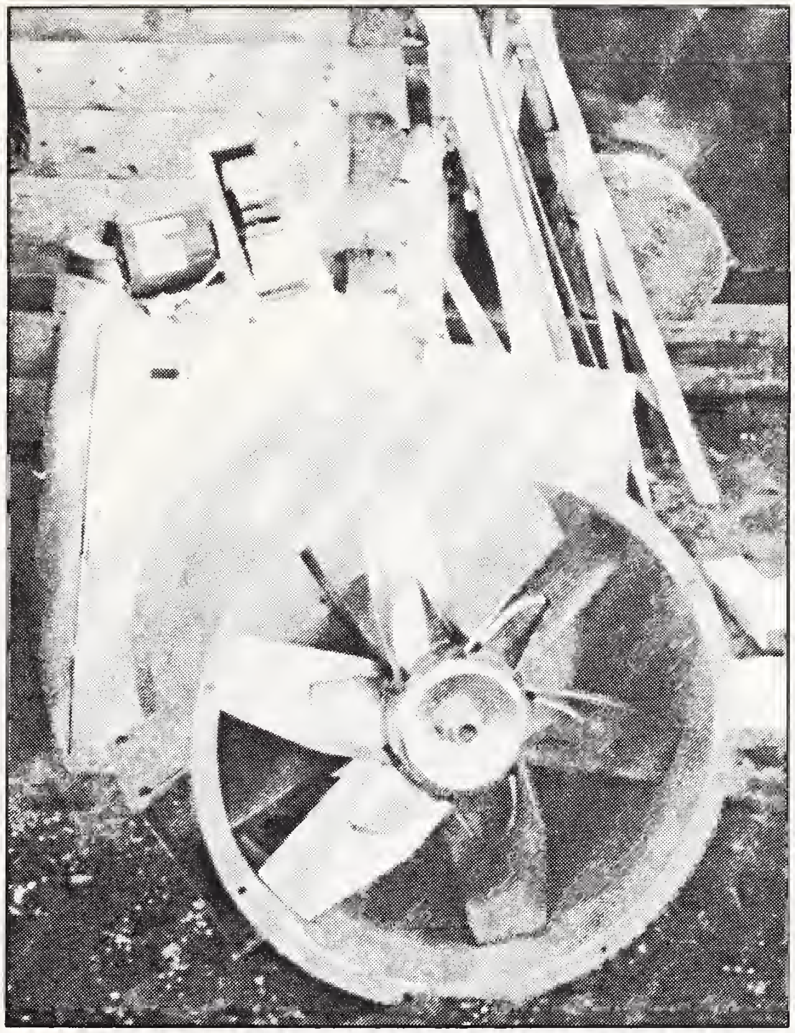


Figure 8. Six-bladed, 30-inch ducted fan ready for installation above plenum.

Grantee has tried pumping water over fabric sacking hung between the two condensing radiators—see Figure 6(D). This technique, however, proved ineffective.

The ducted fans (see Figure 8) are designed to operate efficiently when rotating in one direction only. Because air flow in the kiln must be reversed periodically (four-hour cycle time), the Grantee has turned over one of the two fans. Thus, while somewhat diminishing fan efficiency, air flow through the kiln is maintained at a constant level even when the fan direction is reversed. Although no measured quantitative data are available, correspondence in the file indicates that these two fans were designed to deliver 37,000 cubic feet per minute.

As noted previously, the temperature of the heated air entering the kiln (see Figures 10 and 11 on pages 14 and 15) can be controlled by varying the sawdust burn rate, and the circulation direction can be reversed periodically. Since the system provides no humidity control as included in the design, no conditioning of dried timbers with high-humidity air is possible at the end of kiln runs. Such conditioning sometimes is used to reduce the size of drying checks. Also, high humidity at the beginning of a kiln run is useful in minimizing the development of major checks—a technique not possible with the Grantee's arrangement as it now exists.

Also previously noted, air circulation is reversible vertically via four rows of multiple duct openings in the kiln floor and a single row of openings into the kiln ceiling (see Figures 12 and 13 on pages 15 and 16). The kiln is loaded with forklift units of stickered timbers up to 16 feet long. These packages can be stacked within 18 inches of the ceiling. The timbers are spaced on the sticks horizontally to permit both vertical and horizontal air flow through the stickered packages.

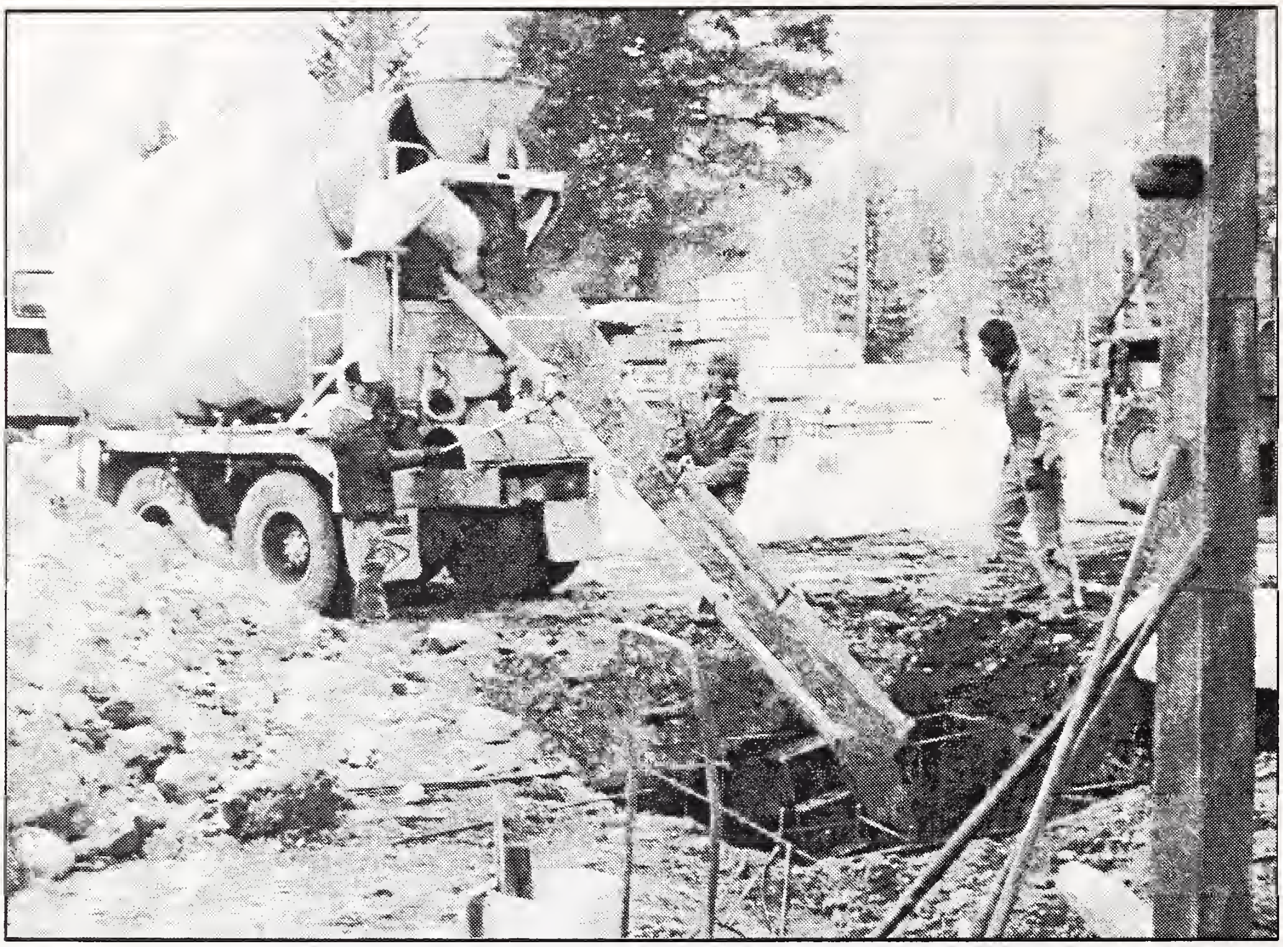


Figure 9. Cement pour during construction of sump tank adjacent to, and below, condensing radiators, which was intended to receive water condensed from moisture-laden kiln exit air.

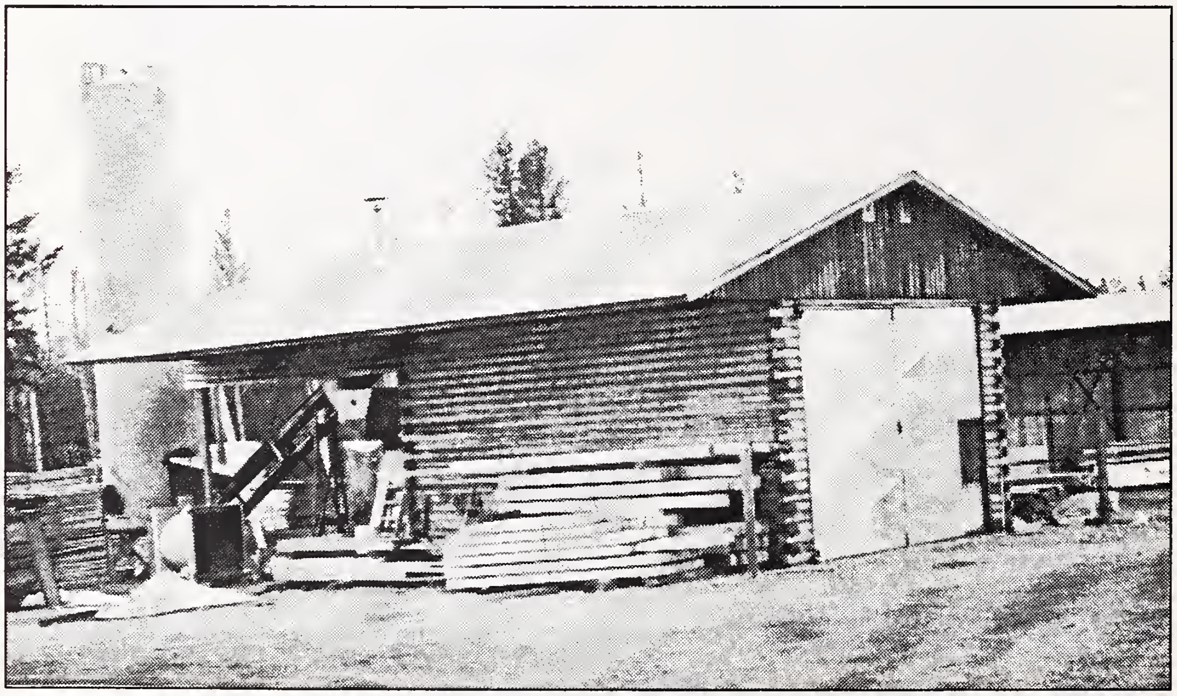


Figure 10. Overall view of the dry kiln and its relationship to the sawdust burner and heat exchanger visible at left. The insulated double kiln doors permit forklift loading and stacking of 16-foot-long packages of stickered timbers.

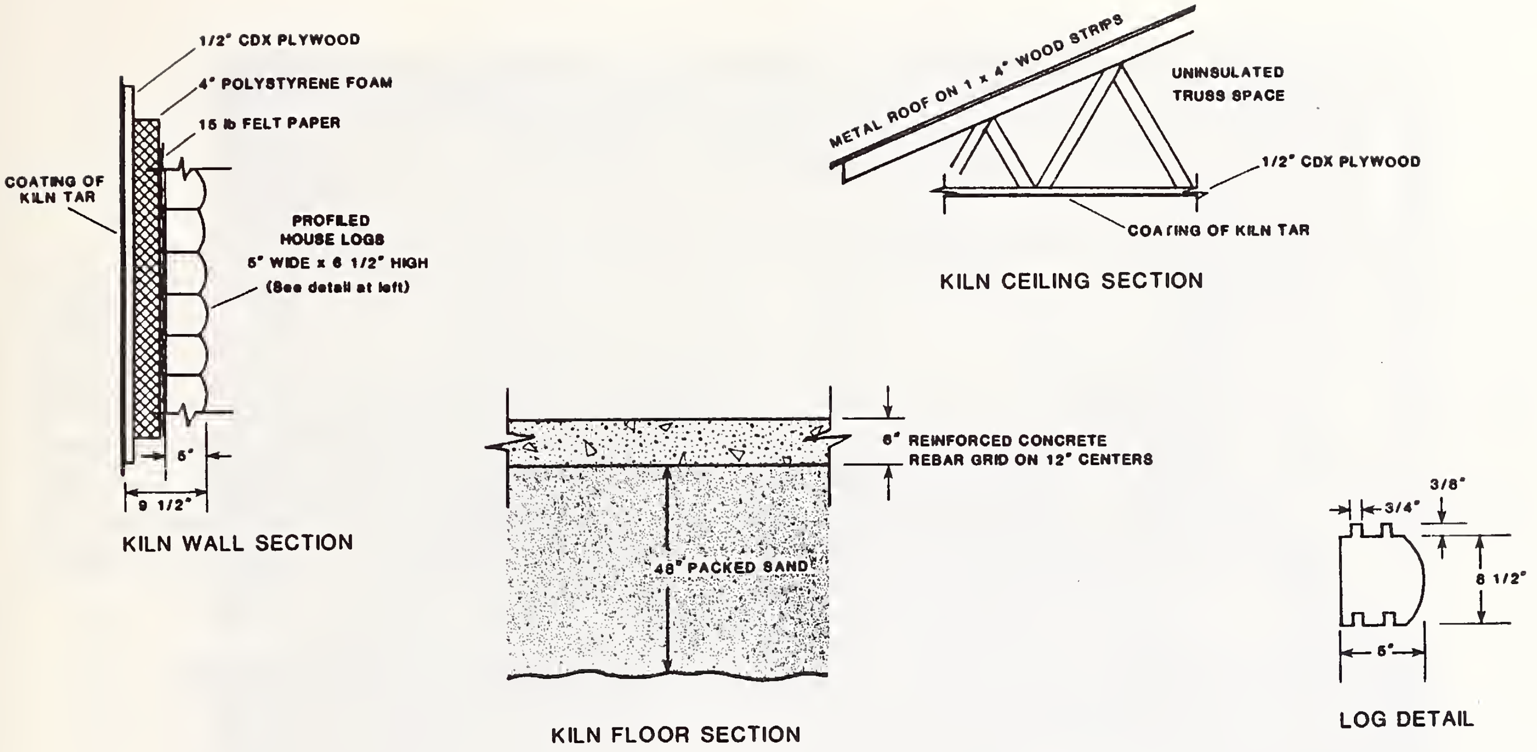


Figure 11. Typical cross-sections through kiln walls, ceiling, and floor of kiln.

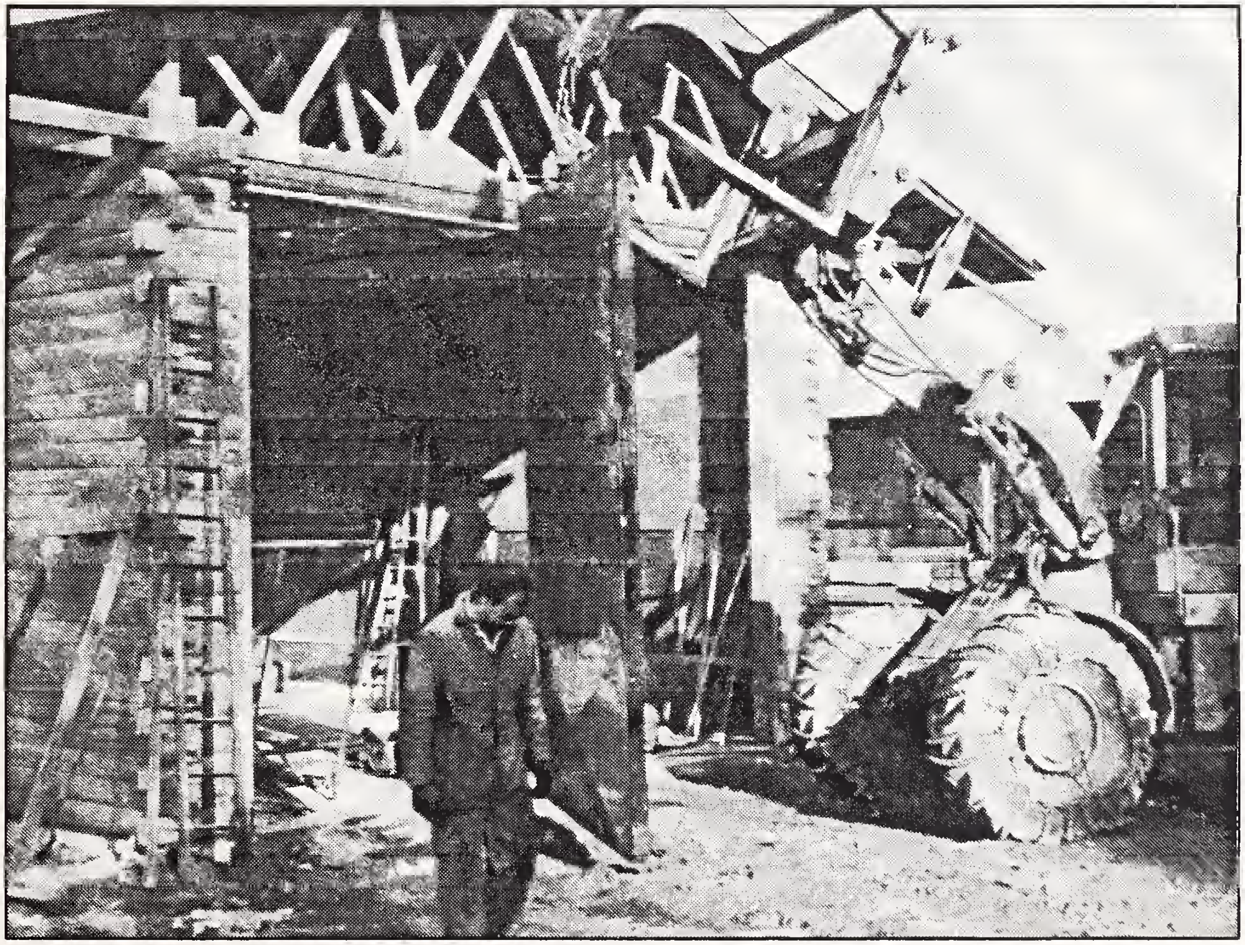


Figure 12. Trussed roof structure in kiln contains single center-run of ported ducting to deliver (or receive) heated air for vertical air circulation. There are no fans internal to the kiln. One-half of the kiln door is suspended for installation.

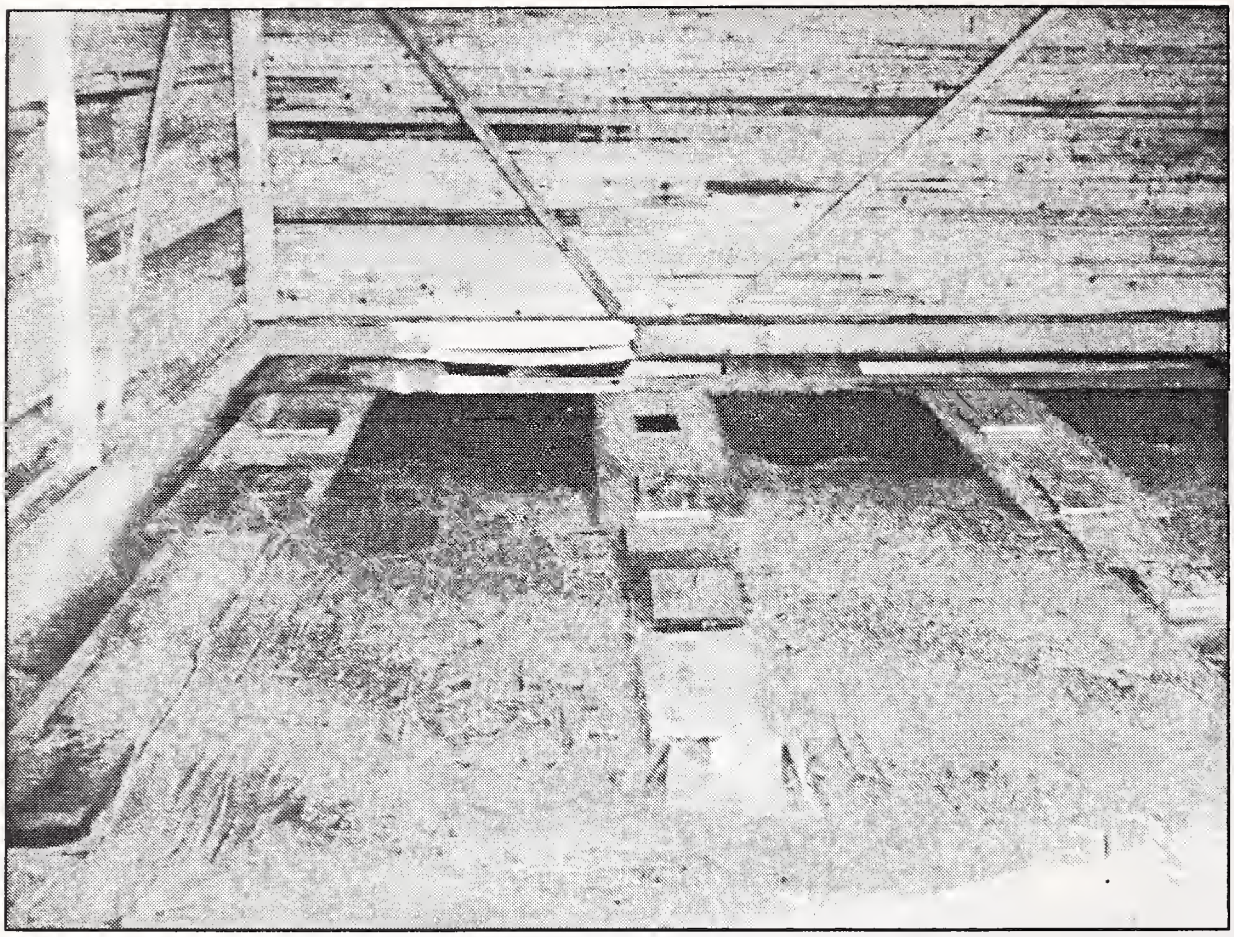


Figure 13. Ducting in concrete floor of kiln to deliver (or receive) heated air from external ducted fans—Figure 6(B) and (C)—for vertical air circulation within kiln. Three of the four floor ducts running the length of the kiln are shown as concrete floor was being poured. Each duct has multiple ports.

The Grantee computed flow to be about 480 feet per minute. Average velocity may be somewhat lower, and velocity variations within the kiln charge likely are substantial. In a forced-air, low-temperature dryer such as this, however, air velocity is less important than that in a high-temperature dryer. The species and size of timbers (mostly 6"-by-6" and 6"-by-8") to be dried, the inability to control relative humidity in the kiln, the need to dry the timbers to about 17 percent moisture content or less, and the need to avoid product degradation from excessive checking all combine to dictate operation of the system as a forced-air, low-temperature dryer with kiln temperatures generally not exceeding 110°F. At least one broad face of each timber (the one that will be shaped to log form and used for the house's exterior surface) must be virtually check-free.

A typical schedule used by the Grantee calls for an initial temperature of 110°F (humidity uncontrolled) held for seven or eight days. The partially air-dried to green timbers forming a typical charge of 40,000 BF require about 30 days total dwell time in the kiln, with the final 22 days held at 70°F (humidity uncontrolled). The Grantee reports no significant difference in drying time between 6"-by-6" timbers and 6"-by-8" timbers. The final moisture content of timbers likely varies significantly within kiln charge, depending in part upon the mix of incoming wood. Quantitative data on this variation, however, are lacking. Extensive experiments to minimize both product degradation and kiln dwell time by manipulating the schedule have not been conducted.

The kiln (see Figure 10) has no roof vents, and the air circulation system is a closed loop. Temperatures are so low and drying is so slow that moisture leaving the timbers reportedly works its way out of the kiln structure with no visible emissions of water vapor.

CONTROL SYSTEM

As noted previously, kiln air temperature is controlled by controlling the sawdust burn rate. This is accomplished by automatically controlling the combustion-air fan and the two induced-draft fans in the flue-gas stack in response to readings of flue gas temperature entering, and kiln air temperature leaving, the heat exchanger. The small combustion-air fan operates more or less continuously, while the two induced-draft fans run intermittently.

To permit the Grantee to follow the progress of drying, remote-reading, moisture-content sensors (shell and core) are inserted into timbers in two packages. Meter readouts can be made at will from the master control panel (see Figure 14). Because the schedule does not automatically adjust to a desired schedule, the Grantee must make schedule adjustments by judging the progress of drying and degradation of the product.

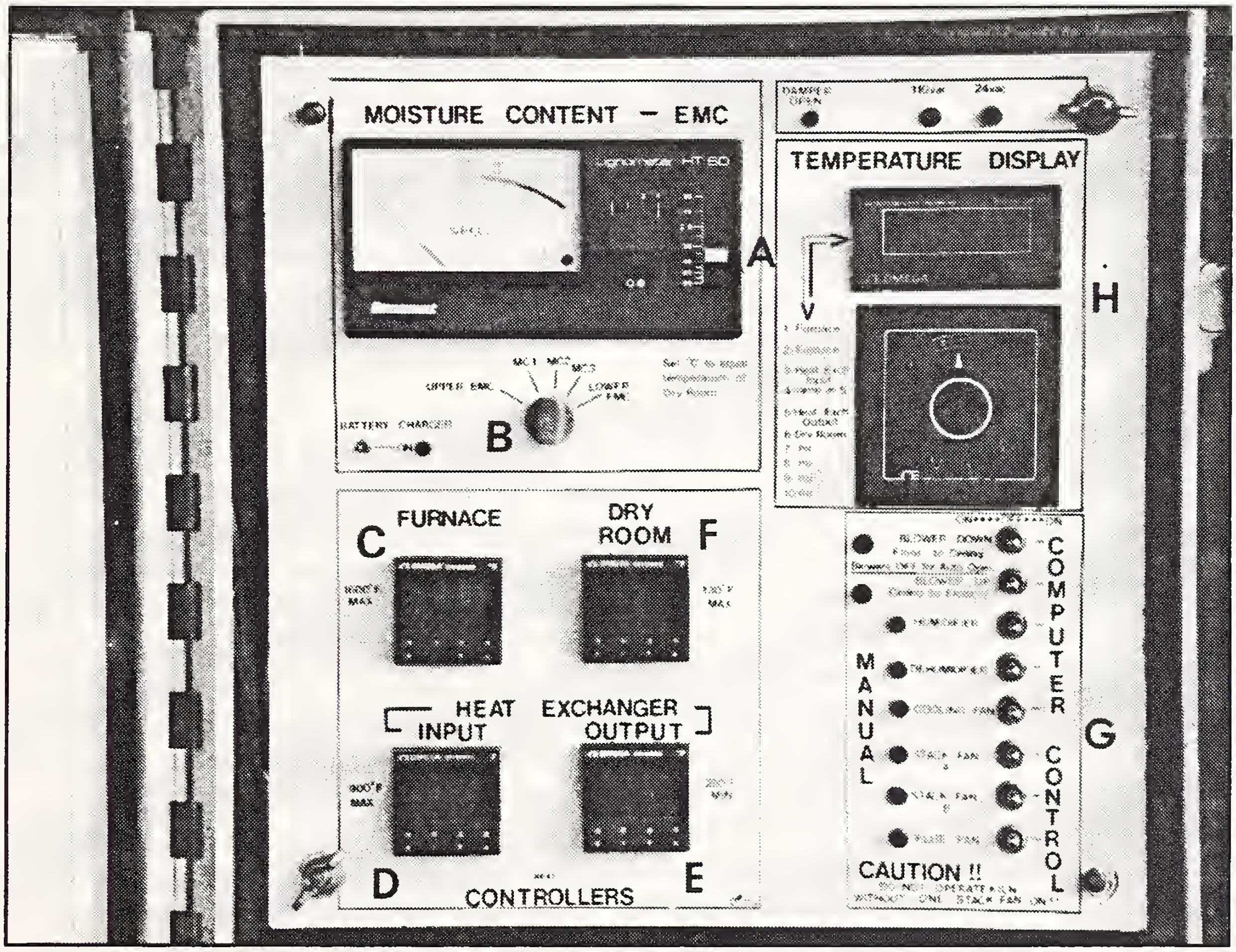


Figure 14. Control panel for system operation (from Grainger Supply, Spokane, Washington). (A) Control manually set to desired kiln temperature. (B) Selector for remote-reading, moisture-content probes (core and shell); two locations. Needle-gage readout above. (C) Temperature of flue gas at furnace (1,400°-1,800°F.) under manual or automatic control; digital readout. (D) Temperature of flue gas going into heat exchanger (700°-900°F.) under manual or automatic control; digital readout. (E) Temperature of flue gas leaving heat exchanger (400°F., minimum 250°F.) under manual or automatic control; digital readout. (F) Kiln temperature digital readout (70°-110°F.) manually set at A, then automatically controlled. (G) Selector switches for automatic or manual control of foregoing temperatures. (H) Redundant digital readout (by selector) of data B through F.

ENERGY REQUIREMENT

Total connected electric-motor HP for the drying system as built is shown in the table below.

Energy demand for lighting in this particular operation is minimal. Some energy is consumed by forklifts that load and unload the kiln—about 0.20 hour of operation/MBF kiln-dried.

The Grantee reports that when the fuel storage bin was filled twice and emptied twice into the burner, fuel was approximately sufficient to dry (to about 17 percent moisture content) one kiln charge of 40,000 BF of partially air-dried timbers. The fuel storage tank has a usable sawdust volume of about 896 cubic feet based on a 6.5-foot inside diameter and 27-foot net inside height. In approximate terms, this suggests that about 45 cubic feet of such sawdust are required to dry 1,000 BF of partially air-dried timbers.

A cubic foot of typical sawdust weighs about 11.5 pounds; the moisture content of one sample amounted to 36.3 percent of oven-dry weight. A cubic foot of this type of sawdust therefore has an oven-dry weight of approximately 8.4 pounds and contains about 3.1 pounds of water. Although these observations are reasonable conjectures, no statistically sound data are available to verify the figures.

At 8.4 pounds of oven-dry wood per cubic foot of sawdust, the foregoing discussion suggests that approximately 378 pounds of sawdust (oven-dry basis) are required per MBF of timber dried. At 8,600 Btu/pound of oven-dry wood, minus the energy required to evaporate the 3.1 pounds of water in each cubic foot of sawdust, an energy input to burner of about 3.25 million Btu results. Since no precise fuel consumption data are available, however, this computation is only a rough approximation.

Item	Connected (HP)	Hours of operation/ 30-day charge cycle	HP hrs. per charge
Star feed to sawdust blower	5	36	180
Sawdust blower	30	36	1,080
Fuel bin anti-bridge gear	5	180	900
Conveyor to sawdust burner	5	36	180
Combustion-air fan	1	720	720
Override cooling fan	0.33	0	0
Induced-draft stack fan #1	0.25	700	175
Induced-draft stack fan #2	0.25	50	13
Ducted kiln fan #1	5	720	3,600
Ducted kiln fan #2	5	720	3,600
Ethylene glycol pump	0.33	Not operational	0
Glycol cooling fan	5	Not operational	0
TOTALS	62.16		10,448

OPERATIONAL EXPENSES AND COMPARISON WITH OTHER SYSTEMS

A manufacturer might consider the following systems as other options for drying 6"-by-6" and 6"-by-8" timbers:

- Air-drying only
- A wood-fired, forced-air, low-temperature dryer similar to that installed by the Grantee
- An electric-powered heat pump with a small auxiliary electric boiler to add additional heat and/or humidity if needed (see Figure 1 on page 4).
- A gas-fired, conventional steam dry kiln in which humidity is controlled.

It should be kept in mind that if the kiln is operated continuously, the Grantee can dry about 12 charges of 40,000 BF of timbers each year, yielding an annual total of about 480,000 BF. At this time, however, it appears that the kiln will be operating intermittently because of an insufficient timber supply.

Using a fairly sophisticated computer model, Wengert and Beckwith (1989) estimated that total drying costs (including product degradation) of the foregoing options in large-scale kilning of southern pine would differ by only a few dollars per MBF dried (a range of $53 to $60 in total cost). Judging from these rather extensive calculations, the annual difference in total operating cost for the Grantee's annual maximum output of 480,000 BF would vary from $25,440 for the least expensive system to $28,800 for the most expensive—an annual difference of $3,360. Using Wengert's and Beckwith's calculations, a forced-air system reasonably similar to that installed by the Grantee proved least expensive. Since heat energy comprises one of the major cost elements, and because sawdust essentially is free to this and most other sawmills, the finding appears reasonable.

With only 480,000 BF of timbers dried per year, projecting drying costs well in excess of $60/MBF is not difficult, as shown in the following table:

Item	Annual cost (Dollars)	Cost/MBF (Dollars)
20-year depreciation of $120,000 capital cost, including forklift	6,000	12.50[5]
Annual interest (profit) on $120,000 at 15%	18,000	37.50
Labor with fringe costs (one quarter-time employee/year)	6,000	12.50
Sawdust cost (lost sales to other outlets)	840	1.75
Electricity for connected motors (10,448 HP Hrs x 12 charges/year at $0.05/HpHr)	6,269	13.06[6]
Maintenance	2,000	4.17
Taxes	1,000	2.08
Insurance	1,000	2.08
TOTAL	**$41,109**	**$85.64**

Firing with natural gas would have lowered the initial investment by about $25,000, but annual energy costs would increase by about $5,877 (3.3 million Btu/MBF feet dried x 480 MBF x $3.71/million Btu for natural gas). Connected motor HP might be cut a little, and maintenance probably would cost somewhat less for the natural gas system. On balance, the natural gas system might cost about the same per MBF kilned as the sawdust-fired system selected.

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[5] Assumes the system essentially could be duplicated with an investment of $120,000.

[6] At one time, the Grantee monitored the system's electrical energy use and concluded that the power cost totaled $.75/operating hour. This suggests a power cost (without provision for humidity control) per MBF dried of about $13.50; that is, $.75 x 24 hrs. x 30 days/40 MBF.

A kiln with an electric heat pump (refrigerator-compressor system) with a small auxiliary boiler would have a capital cost approximately the same as that of the system installed by the Grantee. While humidity control would reduce product degradation and perhaps shorten drying cycles, the additional cost of electric energy for the compressor (40 HP operating 24 hours/day, 365 days/year) compared to the sawdust burner—probably about $32/MBF kiln dried—could well offset those benefits.

With this in mind, it is not difficult to understand why log cabin builders are eager to acquire lodgepole pine and other species of wood that have been insect-killed and air-dried on the stump. Logs from the dead trees, when peeled and stored for several weeks, frequently may have a moisture content that approaches 24 percent. On the other hand, this type of wood may be difficult to procure within the time frame of the builder's production schedule. Also, competition for wood dried on the stump has driven the price in some areas to $100/MBF above that of logs cut from live trees.

A log home may contain 10 MBF of logs or timber. If kiln-drying costs are $85/MBF feet dried (in excess of that incurred with dead wood air-dried), the builder must charge an extra $850 for the house-kit materials—a significant percentage of the kit's sale price.

On the other hand, if the manufacturer must air-dry a $6,000 kit of logs for a year (beyond the month taken to kiln-dry), his inventory interest charge could equal the cost to kiln-dry. Although the solution to the complex cost equation involved is not simple, the fact that few kilns are used for logs or timbers in the log home industry suggests that the economics associated with kilning are not overwhelmingly attractive.

SUGGESTED IMPROVEMENTS

In reviewing the Grantee's project, it seems as though a small, gas-fired boiler designed to inject low-pressure steam into the kiln on demand, coupled with control of wet-bulb temperature, might be worth trying. By this addition, the control of initial and ending kiln relative humidity may permit the schedule to be manipulated to control product degradation and shorten schedules.

Winter heat loss through the uninsulated ceiling of the kiln (and also through the concrete floor) must be substantial. Addition of ceiling insulation that would not become water-soaked from vapor condensed after it passes through the half-inch sheathing plywood would be worth considering. Perhaps a vapor barrier above the plywood sheathing, but below the insulation, would prevent the insulation from becoming water-soaked.

RELATED RESEARCH NEEDS

Conducting controlled studies of various schedules with simultaneous control of the moisture content and size of entering wood would be worthwhile. These studies likely would result in shortened schedules (possibly to three weeks for timbers cut from air-dried logs) and higher annual throughput. This information would show significant value for log-home builders in the Northwest; it also would prove valuable to Montana's post and pole industry. If nothing else, the ethylene glycol condensers system should be tried in low-temperature weather to determine whether the condensing radiators will function as the system designer intended.

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CHRONOLOGICAL LOG OF COMMUNICATIONS IN THE DNRC FILES RELATED TO THE GLACIER LOG HOMES PROJECT

GRANT AGREEMENT RAE-84-1049
February 11, 1986 through March 1, 1991
Prepared by DNRC

1. February 11 through April 17, 1986: Proposals from Machinery Market, Inc., Portland, Oregon, to DNRC and Glacier Log Homes.

2. May 23, 1986: Request from Glacier Log Homes for an amendment to Grant Agreement RAE-84-1049.

3. May 31, 1986: Internal DNRC memo recommending approval of the amendment request for the total amount of $117,108.

4. June 27, 1986: Grant Agreement No RAE-86-1070 sent from DNRC to Glacier Log Homes for signature.

5. July 8, 1986: Fully executed Grant Agreement No. RAE-86-1070 sent by DNRC to Glacier Log Homes (agreement date defined as June 15).

6. (not dated) probably July 1986: A series of purchase agreements between Glacier Log Homes and Ultrafire West of Victor, Montana, for equipment.

7. (not dated) presumably simultaneous with aforementioned purchase agreements. Five sheets of drawings were provided to Glacier Log Homes by Ultrafire West.

8. September 17, 1986: An invoice to DNRC from Beaver Wood Products of Columbia Falls, Montana, for a storage bin.

9. September 18, 1986: Letter from Glacier Log Homes submitting the Milestone 1 and 2 reports, with request for DNRC approval of the system design. Other enclosures include the vendor invoices and the Ultrafire West drawings.

10. October 24, 1986: Letter to Glacier Log Homes from DNRC noting that the Milestone 1 and 2 reports show significant differences from the system described in the original agreement.

11. (not dated—received by DNRC November 14, 1986): Letter from Glacier Log Homes requesting approval of the design change that abandons the heat pump in favor of an external, fan-cooled-ethylene glycol system. Also included is a letter from Ultrafire West, guaranteeing that the equipment would be delivered as specified.

12. December 9, 1986: Letter from DNRC to Glacier Log Homes, approving system changes described in the Milestone 1 report and advising that Milestone 1 charges will be paid on receipt of signed copies of Amendment No. 1 to the agreement.

13. December 15, 1986: Letter to Glacier Log Homes along with fully executed (signed) Amendment No. 1 to Grant Agreement No. RAE-86-1070.

14. February 24, 1987: Letter from Glacier Homes to DNRC along with 15 color slides that describe progress to date on the dry kiln.

15. March 19 (year not indicated, but presumably 1987): DNRC internal memo recommending that Milestone 2 be considered completed.

16. March 30, 1987: DNRC progress report, including budget summary, on the Glacier Log Homes Project.

17. April 6, 1987: Letter from DNRC to Glacier Log Homes outlining kiln energy monitoring parameters.

18. April 8, 1987: Letter from Glacier Log Homes to DNRC requesting reimbursement for Milestone 3 (kiln construction and furnace and dehumidification system installation followed by on-site inspection by DNRC). The letter indicates that a summary of con-

struction and installation procedures was enclosed, but the reviewer's file does not include the summary. Photographs and color slides also were sent with the letter.

19. April 30, 1987: DNRC approval of vendor invoice for Milestone 3 of $70,700.

20. May 11, 1987: DNRC internal progress report on the project, based on an on-site inspection.

21. May 13, 1987: DNRC claim payment authorization for Milestone 3 approved for $60,831.07.

22. June 25, 1987: DNRC status report on project.

23. August 8, 1987: Letter from Ultrafire West to Glacier Log Homes indicating that relationships are far from amicable between the two principals.

24. September 1, 1987: Letter from DNRC to Glacier Log Homes indicating that DNRC requested Ultrafire West to contact Glacier Log Homes about completing the startup phase of its agreement with Ultrafire West.

25. September 9, 1987: Letter from Glacier Log Homes to Ultrafire West requesting a conference to settle differences. Also requested are schematic diagrams of furnace, heating system, control system, and ducting and humidity components.

26. September 13, 1987: Letter from Glacier Log Homes to Frank Piwarski of Ultrafire West advising that the arrangement between Glacier Log Homes and Ultrafire West has apparently ended.

27. September 23, 1987: DNRC status report on project.

28. September 28, 1987: DNRC internal memo discussing options for the project, including names of consultants that Glacier Log Homes might engage.

29. December 15, 1987: DNRC internal memo describing conversation with Glacier Log Homes about the disposition of $5,000 withheld from the Milestone 3 payment.

30. January 20, 1988: Letter to DNRC from Glacier Log Homes requesting payment of the $5,000 withheld from the Milestone 3 payment.

31. February 12, 1988: DNRC approval of claim payment authorization for Milestone 3 in the amount of $5,000.

32. March 2, 1988: Memo from DNRC to Glacier Log Homes reporting results of on-site data collection of January 20, 1988, related to combustor system efficiency.

33. July 18, 1988: DNRC internal memo advising that Glacier Log Homes's sawmill was destroyed by fire but that the kiln building and furnace were unharmed.

34. August 29, 1988: DNRC internal memo relating phone conversation between DNRC and Glacier Log Homes advising that the kiln is not operating because of lack of sawdust fuel from the burned-out sawmill.

35. September 30, 1988: Letter from Glacier Log Homes to DNRC requesting an extension of the basic grant agreement.

36. October 27, 1988: Letter to Glacier Log Homes from DNRC sending Amendment No. 2 for signature.

37. NOTE: The file includes no record of communications during 1989.

38. December 11, 1990: Letter from DNRC to Glacier Log Homes comprising Appendix B to Agreement No. RAE 86-1070, Assignment of Monitoring and Final Reports.

39. January 29, 1998: Internal DNRC memo addressing the problem of engaging a consultant to prepare a final report on the Glacier Log Homes Project. The memo indicates a desire for a camera-ready report to be printed in limited number (e.g., 150 copies) for presentation at a national bioenergy meeting. (Reviewer's note: Project results do not warrant presentation at a technical meeting subject to peer review. Instead, presentation at a conference for administrators to illustrate the pitfalls inherent in projects based on initial technical misconceptions would be more appropriate.)

40. March 1, 1991: DNRC schedule of DNRC disbursements to date on the Glacier Log Homes project.